WOOD · WATER · FORAGE · WILDLIFE · RECREATION

FOREST SERVICE
U S
DEPARTMENT OF AGRICULTURE

1905 - 1955

50 YEARS

GOLDEN ANNIVERSARY

OCCASIONAL PAPER 145 1955

BETTER DIAGNOSIS AND PRESCRIPTION IN SOUTHERN FOREST MANAGEMENT

L. R. Grosenbaugh

SOUTHERN FOREST EXPERIMENT STATION
Philip A. Briegleb, Director
Forest Service, U. S. Department of Agriculture

CONTENTS

BETTER DIAGNOSIS AND PRESCRIPTION IN SOUTHERN FOREST MANAGEMENT

L. R. Grosenbaugh
Southern Forest Experiment Station

In Brief

This paper discusses why it is neither technically nor administratively desirable to segregate data on most individual stands of trees or to consistently treat stands as units of management. Particularly in the Coastal Plain of the South, stand differences reflect merely differences--such as age, density, or composition--that are likely to be obliterated by cutting and regeneration. Instead of stands, operating areas with meaningful, permanent boundaries and convenient size (40 to 1,000 acres) should be established as the minimum unit for forest management records and prescriptions; however, a single prescription for a record-unit can specify different actions suited to different tree classes and density conditions. Reconnaissance on such record-units should be tailored to answer silvicultural and operational questions instead of merely providing the usual complex tables of frequency and volume by stand type and condition.

Trees should be classified not only by their current individual characteristics but also on the basis of probable future behavior and value. Growing space should be classified as overcrowded, well used, wasted, or occupied by undesirable vegetation. Where growing space is overcrowded, a decision should be made as to which trees are best entitled to it.

Such classifications allow assessment of priorities in forest-management operations and permit development of area and tree-class prescriptions for individual operating areas. Compliance with management-plan volume or area regulation can be ensured with minimum sacrifice of growing stock and maximum attention to regeneration needs. The last section of this paper describes a novel angle-gauge tally and tally-form for efficiently collecting needed silvicultural data.

Stand Classification: an Operationally Inadequate Basis for Prescription

A forester can easily prescribe the harvest of badly damaged, infested, or about-to-die trees without reference to their neighbors. However, he cannot prescribe the harvesting, deadening, pruning, or leaving of healthy trees without reference to their neighbors and the land around them. A practical forester prefers to base his diagnosis on the prevalence of situations and tree classes on an operational area as a whole rather than to make separate diagnoses for each small stand or group of trees he encounters. However, his prescription for several adjoining stands on an operational area can be flexible enough to specify different treatments for different classes of trees and for different densities encountered.

Thus his marking prescription for a given operational area might be to leave certain classes of trees, harvest certain classes of trees, deaden certain other classes of trees (unsalable on that area), and harvest the least desirable tree in any clump exceeding a specified density. On any given area, different stands might be affected differently by the same prescription. On another operational area, another prescription might be adopted--perhaps because of different proportions or densities of various tree classes, different needs for regeneration, variations in brush cover, or different minimum requirements for operable cut.

Many foresters have overlooked the fact that a marking prescription for an operational area will be applied by men capable of judging or measuring tree class (present value and growth or harm potential, size, species, etc.), relative density (overstocked, stocked, understocked), and site class (good, medium, poor for a given species). It is unnecessary to delineate individual stands or tree groups on a map or to keep facts separate for each stand or class of stands, since stands are merely rather nebulous groups of trees and the land they stand on. For the most part, stands are distinguished by differences in age or size distribution, differences in quality, differences in density or stocking, and differences in composition or species. Occasionally this last difference may be a clue to site difference.

Tree classes and stocking conditions can be defined which will reflect nearly all differences in stands. Then a single prescription for an area can specify a treatment for each tree class and each stocking condition in a group of neighboring stands. Although one prescription (or set of rules) is made for a number of stands, it may result in each stand being treated quite differently, if density and distribution of tree classes in each is different. Even species-site interaction can be reflected by

tree classes which recognize a given species as having high potential when found on one site, and low potential when found on another site.

Thus, representative samples of tree-class distribution in several stands can be integrated to picture an aggregate tree-class distribution for the conglomeration. The sample can also reflect the proportion of the operational area that is overstocked or understocked (in terms of basal area, a stocking criterion that is to all intents and purposes independent of age or site). With this picture of a group of stands, it is not hard to specify what should be done to certain tree-classes in whatever stand found, or what should be done to overdense areas in whatever stand found, or what should be done to understocked areas in whatever stand found, or whether the area as a whole would benefit from some treatment that must be applied on an all-or-none basis (prescribed burning, for instance). A single prescription for the area would vary by tree classes (and hence by site) and by density situations, so the same single prescription for a group of stands could result in quite different actions being taken by the marker as he came to stands with different proportions of tree-classes or different densities. Site would be reflected in tree class also--a given species might be desirable on deep alluvial soils or northerly aspects, and undesirable on shallow or sandy soils or southerly aspects.

Such a concept provides for the needed silvicultural flexibility on a tree and density basis without reference to stands. Present stand boundaries tend to disappear rapidly after cutting, girdling, burning, or any treatment that favors reproduction over large areas; hence, delineating stands may contribute little to the future management of an area. Furthermore, it is administratively intolerable to keep track of a hodgepodge of small stands--they are too small for individual timber sales, prescribed burns, access roads, or deadening operations. Finally, maintaining the identity of individual stands or stand-classes greatly complicates inventory without improving sampling precision: there is usually high volume variation within stand-class and poor stand-area determination.

Recognition and delineation of stands has, in recent years, been accomplished almost entirely through interpretation of aerial photos (coupled with some ground reconnaissance). Delineating stands thus (by photo-interpretation, using size, composition, and crown density) adds little to the precision of the necessary ground-sample, because of photo-scale variation, photo-interpreter error, and post-photography changes. However, good aerial photographs are well worth their cost to forest managers. They are of great value for selecting boundaries of and access routes to operating areas, for laying out fire lines, for orientation and travel, for pinpointing pine or hardwood islands, and for excluding non-

forested areas from sampling. Considerable improvement in ground-sampling efficiency results from using aerial photos to map out open or non-forested areas.

The Place of Record-Units in Forest Management

Instead of working with individual stands, the forest manager should adopt convenient and permanent operating areas whose boundaries will be readily identifiable, now and in the future, both on the ground and in pictures. Silvicultural considerations should influence boundaries only when it is obvious that the same kind of silviculture should not be applied to adjoining areas: in such cases some noticeable physiographic difference is usually involved. The range in unit size might be from 40 to 1,000 acres, just so long as the unit boundaries serve to break up the whole property into suitable operating areas for harvesting, fire protection, prescribed burning, and other administrative functions. These operating areas should be the smallest unit for which separate area and volume records are summarized. A single unit need not be homogeneous as to tree-size, age-class, species, site, type, or condition, although management may work toward homogeneity if that is desired. To emphasize that volumes should not be summarized for smaller areas, the name "record-unit" will henceforth be used to denote the minimum area for administrative purposes.

A minimum diagnostic tally for each record-unit should give a quantitative picture of tree density (basal area per acre) in major tree classes meaningful to a manager. More elaborate inventories can estimate tree diameter, length, surface, and volume distribution. The minimum tally should also give a quantitative picture of distribution in space--the relative frequency of clumps needing thinning, the relative frequency of openings with reproduction, and the relative frequency of openings without reproduction. The need and priorities for TSI (timber stand improvement--the deadening of unsalable stems) on each record-unit can be estimated from the basal area occurring in unsalable, undesirable categories, and the operability of the record-unit can be rated according to the relative frequency of threshold operating densities in salable trees whose removal is silviculturally indicated. Inventory by species is not needed except for utilization, harvest, or sales purposes, and the marker's tally will provide this information later.

All of this quantitative information would allow a schedule of relative priorities to be set up for improvement cutting, thinning, TSI, harvest or regeneration cuts, planting or seeding, prescribed burning, etc. Major stand variations or physical detail helpful to logging, planting,

or other activities are often obvious from aerial photos; and this may help in specifying a prescription, but it does not require breakdown of acreage or inventory within a record-unit. Some plot formulae helpful where aerial photos are to be used in excluding non-forested area or in estimating planting acreage are given in Appendix A.

Although it is not silviculturally necessary to convert a record-unit into a homogeneous area of trees essentially homogeneous in size (even-aged) or trees essentially heterogeneous in size (all-aged), efficiency of administration demands one or the other. After an unmanaged, understocked forest has been divided into record-units, initial volume cut for a number of years will be derived from trees removed for improvement, salvage, and cluster-loosening. When record-units in the South begin to show basal areas of 50-100 square feet per acre, understocking ceases to be a major problem and clusters of overcrowded trees tend to appear more frequently.

There are now two efficient courses open to the forest manager. If he decides to carry a wide range of size classes on each record-unit, he will not hesitate to cut any tree or group of trees that he feels cannot be made to attain the rate of growth desired, even though adjacent large trees cannot effectively use space thus provided. This is all-aged management, and when successfully applied should result in little clumps of reproduction springing up as more space is provided than the overstory can use.

Various systems of estimating growth in all-aged stands have been devised. Probably the repeated periodic inventory of permanent point-samples (see Appendix B) or permanent plot-samples (continuous inventory) is the simplest and safest. Periodic cut on a record-unit should be kept less than growth until the desired stocking has been built up. Once this has occurred, the maximum allowable cut can be taken, anticipating mortality and making up the balance of the cut among the most crowded, least promising, and most static trees.

No more will be said about all-aged management, since regulation and record-keeping pose no serious problems in this system. The only serious problems which in some localities militate against all-aged management are physiography (cost of light cut may be too high), obtaining reproduction of the desired species in small openings, and coping with undesired species, heavy litter, rough, or disease without the use of fire. Certain species (such as longleaf pine) and certain areas may require the periodic use of fire; all-aged management will be definitely impracticable in such situations. Also, where reproduction frequently fails to occur or infrequently survives to sapling size, all-aged management may not prove realistic.

The other efficient course open to the forest manager after most of his record-units show basal areas of 50 to 100 square feet per acre is to plan for a time in the future when he will systematically start to regenerate entire record-units in such a way as to lead to equal areas for each age in a progression of age-classes ending with the oldest age-class needed to grow the maximum tree size desired. This is even-aged management, and it involves refraining from creating openings except to anticipate loss or to provide space that can be used by the adjacent overstory. Unless clear-cutting and planting are scheduled, it also involves making preparatory cuts to favor seed production at least 3 to 5 years in advance of a regeneration cut which covers an entire record-unit. The regeneration cut should remove all salable trees except those desired for seed production. Prescribed burns may be found useful just prior to or just after a regeneration cut. Finally, even-aged management involves removing all seed trees or sheltering trees as soon as reproduction is well established, except where the so-called reserve seed-tree method has been incorporated into the owner's policy. With patchy record-units having far less than 50 to 100 square feet per acre of basal area, it may be decided to regenerate at once instead of waiting for a stocking build-up that may never occur without such measures as planting, seeding, site preparation, etc.

With the exception of the grossly understocked and patchy record-units discussed above, a record-unit under the even-aged system might be deemed eligible for regeneration cutting when at least 70 percent of the salable basal area (or some other arbitrary proportion) has attained the age, height, or diameter that is the owner's objective for that average site class. Groups of record-units aggregating about the same area each period should be regenerated periodically after the manager has decided to initiate regeneration cuttings. As a general rule, the grossly understocked units should be regenerated first, followed by the units which first reached eligibility or which most greatly exceeded the eligibility requirements.

Naturally, an estimate must be made of the time between regeneration cut and the time when 70 percent of standing salable basal area attains or surpasses the size set as the goal. This period can be thought of as the rotation. Where seed-years, weather, floods, or fires are apt to be unfavorable year after year, it is important to advance or postpone scheduled regeneration cuts so as to take advantage of favorable circumstances. Partial cutting in other stands can be accelerated or decelerated to balance overages or deficiencies in area regenerated annually. It is obvious that variation in "waiting periods" will make any precise calculation of rotation illusory, as will variation in height growth among sites and variation in diameter growth among stands of

different density. If it is desired to narrow the difference in size between managed compartments at a fixed rotation age, management can speed up attainment of a given diameter (by thinning) or a given merchantable height (by pruning).

Occasionally under the even-aged system it will be impossible to make regeneration cuts on equal areas at regular intervals without considerable sacrifice. This situation will usually be caused by the excessively premature or excessively postmature character of the record-units most nearly meeting the eligibility specifications. It might be advisable to regenerate a greater area of postmature units than called for, or a smaller area of premature units. This may prevent securing a balanced age-class distribution in the first rotation, but the peaks and troughs in the harvest cut can be levelled off by making lighter or heavier partial cuts in record-units not being regenerated during such periods of abnormal regeneration cutting.

Before going further, it would be well to define some illustrative tree classes for use in a management cruise. A set of definitions like that on the next page will allow prescriptions to be made and priorities to be set, and will greatly simplify a silvicultural inventory.

The proposed tree-class code names are short, suggestive, and systematic. They avoid commonly used "woods language," which has already suffered from loose usage or ambiguity--terms such as cull, overburden, etc.

Other definitions than those given below may be used, depending on the owner's desires and objectives, but the general idea of priorities is basic. Whatever quantitative definitions are used, it is obvious that assignment to classes based on expected future behavior will be more or less subjective, depending on past experience and intuition. Inventory according to prognosticated tree classes will be helpful, however, because it estimates the desirability and magnitude of the following jobs: (1) salvaging static, lessening, or threatened values; (2) providing adequate growing space for valuable or potentially valuable trees by removal of less valuable Payers or Cruds; (3) regenerating stands which are not utilizing space adequately; (4) doing other silvicultural jobs. Prescriptions based on such inventory may include cutting, girdling, poisoning, pruning, burning, ground disturbance, soil amendment, seeding, planting, and grafting.

GROWN-UP: A tree of salable dimensions, whose salability depends on other factors.

PAYER: A salable tree--one whose stumpage has a current market value greater than zero. When it cannot be established by actual bid of prospective purchaser, locally acceptable minima must be arbitrarily specified; specifications should cover species, tree dimension and shape, quantity of acceptable products per tree, description of minimum acceptable product, proportion of harvested bole which must yield acceptable products, maximum allowable product defects such as knots, decay, stain, insects, etc.

Grower: A payer whose expectancy of living for the next 10 years is at least $\frac{9}{10}$ while its expected ratio of $\frac{\text{stumpage value 10 years hence}}{\text{stumpage value now}}$ will be at least $\frac{4}{3}$ if it survives and is given adequate space. Obviously, the expected future value of such a tree is at least $\frac{9}{10} \times \frac{4}{3} = \frac{6}{5}$ current value, or an increase at the rate of at least 1.8 percent compound interest. Characteristics or symptoms useful in classifying trees as growers include size, form, species, site, vigor (crown, bark, root), and freedom from knots, lean, serious pathogens, etc. Some people call such trees "crop trees" or "good growing stock." It is not difficult to calculate the ratio of $\frac{\text{volume 10 years hence}}{\text{volume now}} = \frac{(D-N)^2\ N}{(d-n)^2\ n}$ if one postulates the d.b.h. and number-of-log increase from d to D and from n to N in 10 years; the ratio thus calculated assumes volume measured in board feet (Int. 1/4-inch rule). Of course, increment in value due to factors other than volume growth (such as price inflation, quality improvement, lower unit operating costs) must be guessed, and is usually ignored. Schneider's somewhat simpler approximation is: Growth percent = $\frac{400}{DR}$, where D is d.b.h. in inches and R is number of rings per inch; DR should not exceed 133 when growth of more than 3 percent is desired.

Cipher: A payer whose expectancy of living for the next 10-year period exceeds $\frac{9}{10}$, but which does not have an expected ratio of $\frac{\text{stumpage value 10 years hence}}{\text{stumpage value now}}$ equal to at least $\frac{4}{3}$, and which does not compete with any grower, doll, or cub (see below). Some people call such trees "financially mature."

Topper: A payer similar to a cipher but overtopping a doll or cub (see below).

Slower: The least potentially productive of several payers (not riskers or killers--see below) competing in inadequate growing space. It should be cut in thinning.

Risker: A payer whose expectancy of living for the next 10-year period is less than $\frac{9}{10}$. It should be cut to salvage potential loss through mortality.

Killer: A payer infested with contagious pathogens.

CRUD: A grown-up which cannot be sold because of species, form, knots, rot, insects, or other defects.

Null: A crud not competing with any grower, doll, or cub (see below).

Cork: A crud overtopping a doll or cub (see below).

Pang: A crud seriously competing with a grower or harboring contagious pathogens.

DEB: A tree at least 4-1/2 feet tall but smaller than a grown-up.

Doll: A desirable deb which is a potential grower, given adequate space and time.

Drip: An undesirable deb which is unlikely to become a grower, even though given space and time, but which is not interfering with a doll or cub (see below).

Drag: An undesirable deb which is interfering with a doll or cub (see below).

KID: A tree seedling less than 4-1/2 feet tall.

Cub: A desirable kid which is a potential doll.

Cur: An undesirable kid which will probably become a drip or drag.

Regulated intermediate periodic cutting of merchantable material should not take place till the entire working circle has been covered by an initial improvement cut; subsequent regulated intermediate-plus-regeneration cuts should not exceed allowable cut for the working circle unless unusual salvage operations are required. Regulated intermediate cuts should be allocated to record-units with the greatest operable cut of Killers, Riskers, and Slowers. In even-aged management, Toppers and Ciphers should not be removed by intermediate cuts unless operability of an area hinges on cutting them, or unless their harvest will tend to iron out fluctuations in cut during conversion period; in uneven-aged management they can be removed up to the limits of allowable cut. Occurrence of numerous Toppers may influence decision to regenerate early so as to take advantage of existing reproduction, or may predispose toward changing from even-aged to all-aged system. Regulated regeneration cuts in even-aged management should be aimed at getting a balanced acreage of age-classes, always cutting the most eligible record-units as needed to make up the desired acreage. If all-aged management is successful, there is never any need to make regeneration cuts over an entire record-unit at once, since wherever more space is made available than established trees can use, new reproduction will spring up; this should be a continuous process that never leaves any large area unstocked.

Point Sampling and Diagnosis

Point sampling (as explained in Appendix B) will greatly simplify a silvicultural and management reconnaissance, and will provide all the volume data needed prior to the usual tree tally made at time of marking. At every sample point, a tree tally should be made with each of two angle-gauges, for quite different purposes. The most useful sizes for gauges in medium-sized timber not excessively open, dense, or brushy will probably be 104.18 minutes or 3.03 diopters (basal area factor 10, plot radius factor 2.75, crossarm length factor .0303, calibration distance factor 33.0), and 233 minutes or 6.79 diopters (basal area factor 50, plot radius factor 1.23, crossarm length factor .0678, calibration distance factor 14.75). Other gauges can be used where local experience so indicates, or where different range in optimum density is desired. Table 2 in Appendix B lists a wide range of gauges and corresponding factors. Whatever angle-gauge is used, it should be calibrated as described on page 21 of Appendix B or by using Table 3.

The usual tally of Grown-ups and Debs will be made with the smaller gauge (BA factor = 10); this tally will separate trees into at least the major classes of Payers or Crud, Dolls or other. Recognition of more classes will be desirable where any cutting or TSI is contemplated

in the near future. A suitable tally form is illustrated on page 15. Operability under conservative marking prescription may be judged by the proportion or grouping of points having at least one Payer that is tallied as other than a Grower. Until experience dictates otherwise, a count of one such tree should make the point "operable".

The merchantable height (in terms of number of 16-foot logs and half-logs) of qualifying sawtimber Payers should be tallied, and the total height (to the nearest 10 feet) of qualifying pulpwood Payers should be tallied. (This allows separate estimates of sawtimber and pulpwood volumes to be made with simple techniques.) Other qualifying trees should be tallied merely as dots. If the angle-gauge does not automatically compensate for slope of over 10 percent, Table 4 in Appendix B will be found useful to get an average slope correction factor which can be applied to total volumes and basal areas; individual correction factors can be applied to each point-tally, but such refinement is rarely justified.

The larger gauge (BA factor = 50) should be used for a special silvicultural determination at each point--to determine the need for thinning where Payers and Dolls are present and the need for reproduction or TSI where Payers and Dolls are absent. If 3 or more Payers or Dolls are counted at a point, thinning is usually desirable and the tally should be starred; if 1 or 2 are tallied, thinning is rarely needed. A zero tally indicates need for reproduction. A 1/250-acre circle (radius 7.45 feet) should be examined at all such zero-tally points and any Cubs should be tallied; the number should be enclosed in a square if all Cubs need release. If the absolute minimum reproduction considered satisfactory in openings should be something other than 250 well-distributed seedlings per acre, Table 1 in Appendix A can be used to get radius or side of the appropriate plot. Where the desired plot acreage is not shown in the table, but where it can be obtained by dividing a tabled acreage by some perfect square, the tabled plot side or plot radius should be divided by the square root of the perfect square. Thus, if the radius of a 1/250-acre plot had not been tabled, it could have been calculated by dividing 1/10-acre by 25, and its radius by 5. Similarly, finding the radius of a 1/500-acre plot merely requires dividing the tabled radius of a 1/5-acre plot by 10, etc.

Record-units with more than 25 percent of their points having zero counts of Payers and Dolls according to the large gauge and zero Cubs within 7.45 feet of such sample points should be considered as needing special measures--possibly prescribed burning, TSI, scarification, interplanting, or spot seeding.

Record-units with more than 50 percent of points in such doubly sad condition should be considered for heavy TSI, some form of seedbed preparation, and regeneration cutting followed by complete planting if reproduction is unsatisfactory. It may be more profitable to start all over than to waste the land area of the record-unit on such an understocked, non-reproducing stand. This is an economic determination which will differ for each area depending on (1) interest rates specified, (2) cost and probable success of most efficient regeneration techniques, (3) probable economic returns from regenerated stand as compared with returns from existing stand. Hypothetical answers can be worked out for any desired arbitrary interest rate, assumed costs, and assumed yields. Certainty of planting success, cheap planting costs, rapid growth rates, and low interest rates will tend to cause the minimum acceptable stocking to be set at a higher level. However, these are determinations which must be based on owner preference and local experience.

The larger angle-gauge (BA factor = 50) can also be used later on by the marker in actually deciding which clumps should be "loosened" by marking one or more trees for cutting. When the large gauge is thus used in marking for thinning, point-sample counts should be taken in areas of maximum clustering or overlap. Where 3 or more trees are tallied, those least qualified for retention should be marked, so that no more than 2 residual trees can be tallied with the angle-gauge at <u>any</u> point. When no tally greater than 2 occurs (though there must be some <u>less</u> than 2), the maximum <u>average</u> amount of unclustered basal area of uniform d. b. h. left over an area cannot exceed about 83 square feet per acre. In stands where d. b. h. varies but no tally is greater than 2, the maximum average basal area per acre could theoretically more nearly approach 100 square feet per acre. These figures assume a prism with BA factor exactly 50. Of course, prescriptions for different maximum densities would require angle-gauges of different sizes.

Example of Diagnostic Tally

A simple design for an angle-gauge reconnaissance of a record-unit is discussed below to show how diagnostic data are accumulated with a minimum of field and office work, and how costs and priorities can be estimated. The reconnaissance would require a minimum of about 20 unbiased sample points well distributed throughout the record-unit for a standard error of about $\pm$ 25 percent in volume per record-unit. A volume total for 25 such record-units would have a standard sampling error of only about $\pm$ 5 percent for the ownership or working circle as a whole. Each point should be occupied and tallied separately,

with the small angle-gauge (BA factor = 10) according to the tree classes previously defined on a tally form such as that on page 15. Payers should be tallied by number of merchantable 16-foot logs (to nearest 1/2 log) if large enough for sawlogs, and by total height (to nearest 10 feet) if of pulpwood size. Non-payers should be tallied with a dot, as should trees qualifying on the separate tally made with the larger angle-gauge (BA factor = 50).

A tally of 5 sample-points (illustrated for simplicity instead of all 20 points) might appear as in the upper part of the form shown on page 14.

Sawlog and pulpwood trees would be counted separately in each tree class, total heights would be summed separately in each class, and the number of logs would be summed separately in each class. The sums and the tree count comprising each would be recorded in the first three lines of the PER ACRE SUMMARY shown in the middle of page 14.

Conversion factors would be calculated as follows:

For a given tree class, basal area per acre (square feet) would be estimated by tree count, multiplied by instrument BA factor, divided by number of sample points in record-unit (5 in the illustration).

For a given tree class, rough cords per acre (128 cubic feet of wood, air, and bark) would be estimated by total height sum, multiplied by .005 times instrument BA factor, divided by number of sample points in record-unit. This assumes a volume table comparable to MacKinney and Chaiken's Table 5 for loblolly pine (8)[1/].

For a given tree class, gross board feet per acre (Int. 1/4-inch rule) would be estimated by merchantable height sum, multiplied by 60 times instrument BA factor, divided by number of sample points in record-unit. This assumes that diameter and tree form tend to increase with merchantable height. If desired, peeled cubic feet in the sawlog portion of the tree might have been similarly estimated by adding 1/4 sawtimber tree count to merchantable height sum and multiplying by 8 times the instrument BA factor divided by the number of sample points.

Factors more locally valid than .005 and 60 can be substituted by taking some representative areas and measuring pulpwood and sawtimber trees thereon.

1/ Underscored numbers in parentheses refer to Literature Cited, page 27.

$$\frac{\Sigma\,(\text{Cord volumes})}{\Sigma\,(\text{BA})(\text{Total height})}$$ can then be used instead of .005, and

$$\frac{\Sigma\,(\text{Volume})}{\Sigma\,(\text{BA})(\text{Merchantable height} + \text{Constant})}$$ can be used instead of 60.

If factors are to be calculated from K sample trees selected by angle-gauge instead of on an area basis, the factor would be calculated $\frac{1}{K}\sum^{K}\frac{(\text{Cord volume})}{(\text{BA})(\text{Total height})}$, etc., with a ratio being calculated for each sample tree before addition; these ratios would then be averaged for the K trees comprising the sample. Even without a sampling of the local factors, expert judgment may suggest raising or lowering the figures by 5, 10, or 15 percent to allow for known differences in form class, upper-log taper, or defect.

In the example shown on page 14, with instrument BA factor 10, the basal area, cord, and board-foot factors per tallied tree or unit length work out as shown at the bottom of the tally. With these factors, the tree count, total height, and number of logs for any class can be converted to basal area, cords, or board feet for diagnostic purposes.

To illustrate, there would be 1,800 board feet per acre of Growers on the sample tally shown on page 14, obtained as (15)(120) = 1,800 board feet. Similarly, there would be 3,780 board feet per acre of Payers. If only sawtimber can be sold, and if it were desired to mark only Slowers, Riskers, and Killers, the cut per acre would be (540 + 300 + 300) = 1,140 board feet, but 40 percent of the area would be inoperable (i.e., would yield no cut). Prescribing complete TSI of Pangs, Corks, Nulls, Drags, and Drips would involve 16 square feet per acre, 8 square feet of which would be in small Drags or Drips (probably susceptible to prescribed fire, if fuels and watershed considerations permit; there are few Cubs to suffer). The 20 percent of points having large-gauge tally with three or more trees is a measure of occurrence of overdense clusters. The 40 percent of the large-gauge tally lacking Payers, Dolls, or Cubs indicates the need for measures to secure desirable regeneration. Logging and TSI may remedy this, but more drastic measures might be needed. Local experience will govern the specific prescription, but the data allow a diagnosis and a general prescription. Had the slope on the area sampled by the 5 points averaged 25 percent, all volume estimates would have been increased by 3 percent (see Table 4 in Appendix B).

Many other silviculturally useful facts can be derived from the tally. Marking can be prescribed which will secure an operable cut

with minimum inroads into desirable growing stock. TSI prescription and cost estimates can be made from the basal area in undesirable tree classes. Relative priority of thinning needs or regeneration cuts can be established by comparing number of starred or zero large-gauge tallies on a number of record-units.

ILLUSTRATIVE DIAGNOSTIC TALLY

B.A. FACTOR 10
ANGLE GAUGE
TALLY
Tolly totol height in feet of subsowlog (pulpwood) size trees
Tolly number of 16-foot logs of sowlog-size trees

B.A. 50 GAUGE TALLY (only Dolls, Poyers) O = zero ✱ = cluster

1/250 - ACRE PLOT REPRO. TALLY (only of zero points) □ = needs TSI

Point Number	Possible TSI: Pong	Cork	Null	Drag	Drip	Leave: Doll	GROWER	Possible Cut: CIPHER	TOPPER	Cut: SLOWER	RISKER	KILLER	B.A. 50 Gauge Tally	Cub	Cur
1	•			•		•	40 3 / 3		1	1½ / 2	30 2½		••• 3 ✱		
2		•		•			50	4					0	•• $\boxed{2}$	:: 4
3			•	•	•		2½					2½	0	—	—
4							4	2			60 / 70		0	—	7
5	•					••	50 1 / 60 / 60 1½			1			•• 2		

PER-ACRE SUMMARY

	Pong	Cork	Null	Drag	Drip	Doll	GROWER		CIPHER	TOPPER	SLOWER	RISKER		KILLER		
ΣHts.							260					160				
ΣLogs								15	6	1	4½		2½	2½		
ΣTrs.	2	1	1	3	1	3	5	6	2	1	3	3	1	1	33	Totol Tree Count
Bd Ft.								1800	720	120	540		300	300	3,780	Bd. Ft. Totol
Cords							2.6					1.6			+ 4.2	Cords Total
B.A.	4	2	2	6	2	6	10	12	4	2	6	6	2	2	66	Sq. Ft. Totol

CONVERSION CALCULATIONS

$$\text{Bd. Ft.} = (60)\left(\frac{\text{Instrument factor}}{\text{Number of points}}\right)(\Sigma\ \text{Logs}) = 120\,(\Sigma\ \text{Logs})$$

$$\text{Cords} = (.005)\left(\frac{\text{Instrument factor}}{\text{Number of points}}\right)(\Sigma\ \text{Hts}) = .01\,(\Sigma\ \text{Hts.})$$

$$\text{Basal Area} = \left(\frac{\text{Instrument factor}}{\text{Number of points}}\right)(\Sigma\ \text{Trs.}) = 2\,(\Sigma\ \text{Trs.})$$

Factors 30, $\frac{1}{400}$, and $\frac{1}{2}$ would have replaced above factors 120, .01, and 2 if number of points had been 20 instead of 5.

DIAGNOSTIC TALLY

B.A. FACTOR ______
ANGLE GAUGE
TALLY
Tolly totol height in feet of subsowlog (pulpwood) size trees.
Tolly number of 16-foot logs of sowlog-size trees.

B.A. ____ GAUGE TALLY (only Dolls, Poyers) O = zero ✳ = cluster

______ ACRE PLOT REPRO. TALLY (only at zero points) □ = needs TSI

Point Number	POSSIBLE TSI					LEAVE		POSSIBLE CUT		CUT			B.A. GAUGE TALLY	ACRE PLOT REPRO. TALLY	
	Pang	Cork	Null	Drag	Drip	Doll	GROWER	CIPHER	TOPPER	SLOWER	RISKER	KILLER		Cub	Cur
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															
11															
12															
13															
14															
15															
16															
17															
18															
19															
20															

PER-ACRE SUMMARY

ΣHts.													
ΣLogs													
ΣTrs.													Totol Tree Count
Bd.Ft.													Bd. Ft. Totol
Cords													Cords Totol
B.A.													Sq. Ft. Totol

APPENDIX A

GROUNDPLOT AND AERIAL-PHOTOPLOT SAMPLING

Groundplot Formulae

$$\text{Square groundplot side} = 208.7103256\sqrt{\text{Groundplot acreage}}$$
$$\text{Circular groundplot radius} = 117.7521917\sqrt{\text{Groundplot acreage}}$$

Aerial-Photoplot Formulae

RFD = representative fraction denominator (i. e., if photo or map scale is 1: 20, 000, then RFD = 20, 000).

$$\text{Ground-miles per photo-inch} = \frac{\text{RFD}}{63,360}$$

$$\text{Photo-inches per ground-mile} = \frac{63,360}{\text{RFD}}$$

- -

$$\text{Square photoplot side in inches} = \frac{2504.52391\sqrt{\text{Groundplot acreage}}}{\text{RFD}}$$

$$\text{Circular photoplot radius in inches} = \frac{1413.02630\sqrt{\text{Groundplot acreage}}}{\text{RFD}}$$

- -

$$\text{Square groundplot acreage} = \frac{(\square \text{ photoplot side in inches})^2 (\text{RFD})^2}{6,272,640}$$

$$= 640\left[\frac{\square \text{ photoplot side in inches}}{\text{photo-inches per ground-mile}}\right]^2$$

$$\text{Circular groundplot acreage} = \frac{(\odot \text{ photoplot radius in inches})^2 (\text{RFD})^2}{1,996,643.32}$$

$$= 2010.61930\left[\frac{\odot \text{photoplot radius in inches}}{\text{photo-inches per ground-mile}}\right]^2$$

- -

If points or dots on a transparency are in a square pattern or grid and are classified as to some characteristic of an underlying photo (or map), then the acres represented by a single dot are the same as the acres in each square plot made by connecting 4 adjacent dots. Thus:

$$\text{Acres per classified dot} = \frac{(\square \text{ dot-spacing in inches})^2 (\text{RFD})^2}{6,272,640}$$

$$= 640\left[\frac{\square \text{ dot-spacing in inches}}{\text{photo-inches per ground-mile}}\right]^2$$

Table 1.--Dimensions for square or round plots

Areas and dimensions of plots which are convenient fractions of an acre		
Plot area (acres)	Square plot side	Circular plot radius
	Feet	Feet
1/1	208.7103	117.7522
1/2	147.5805	83.2634
1/3	120.4990	67.9843
1/4	104.3552	58.8761
1/5	93.3381	52.6604
1/6	85.2056	48.0721
1/7	78.8851	44.5061
1/8	73.7902	41.6317
1/9	69.5701	39.2507
1/10	66.0000	37.2365
1/12	60.2495	33.9921
1/20	46.6690	26.3302
1/30	38.1051	21.4985
1/40	33.0000	18.6183
1/50	29.5161	16.6527
1/60	26.9444	15.2017
1/70	24.9457	14.0741
1/80	23.3345	13.1651
1/90	22.0000	12.4122
1/100	20.8710	11.7752
1/120	19.0526	10.7493
1/250	13.2000	7.4473
1/500	9.3338	5.2660

Areas and dimensions of plots which are decimal multiples of an acre		
Plot area (acres)	Square plot side	Circular plot radius
	Feet	Feet
100.	2087.1033	1177.5219
10.	660.0000	372.3651
1.	208.7103	117.7522
.1	66.0000	37.2365
.01	20.8710	11.7752
.001	6.6000	3.7237
.0001	2.0871	1.1775
.00001	.6600	.3724
.000001	.2087	.1178

Areas and dimensions of plots where decimal multiples of grams per plot equal pounds per acre			
Plot area (acres)	Square plot side	Circular plot radius	Multiply grams per plot by:
	Feet	Feet	Factor
.00220462	9.7996	5.5289	1
.000220462	3.0989	1.7484	10
.0000220462	.9800	.5529	100
.00000220462	.3099	.1748	1000

$$\frac{453.59243}{43,560} = 1 \text{ pound per acre}$$

= 1 gram per 96.03335 sq.ft.

= 453.59243 grams per acre

= .01041305 grams per sq.ft.

Convenient cylinder sizes for soil sampling

Diameter 4.1962 in. gives lbs. per acre = 1,000 (grams per cylinder)

Diameter 2.8261 in. gives units per acre = 1,000,000 (units per cylinder)

Diameter 2.7874 in. gives in. of water = $\frac{\text{grams of water per cylinder}}{100}$

Diameter 1.4841 in. gives in. of water = ounces (avdp) of water per cylinder

APPENDIX B

POINT-SAMPLING THEORY, APPLICATION, AND TABLES

Point-Sampling Theory

The idea of using an angle-gauge to measure a plot radius which varied with tree size was originated by Bitterlich (1). He showed that the number of trees inside concentric plots (whose radii depended on tree size) tended to be proportional to tree basal area density, which was estimated by multiplying the count of trees whose diameters appeared larger than the angle-gauge by a factor appropriate to the angle-gauge. He later devised several angle-gauges which compensated for slope (2, 3).

Grosenbaugh (5) proposed a concept to replace that of variable-plot-radius. This new concept recognized the fact that an angle-gauge was really a point-sampling device rather than a plot-sampling device. He postulated that a given angle-gauge delineated huge "rings" around trees, with each "ring" diameter being K times its tree diameter, and each "ring" area being K^2 times its tree basal area; a large K was associated with a small angle. An observer standing at a sampling point would then determine (by means of his angle-gauge) within which tree "rings" his sampling point lay (since usually multiple "rings" overlap). The point-sampling concept left no doubt about the kind of sampling being used--it was sampling with probability proportional to basal area (instead of proportional to frequency, as in plot-sampling). This concept was responsible for new and direct techniques for estimating frequency, volume, and growth per acre, as well as some shortcuts (6).

Müller (9) first visualized the advantage of using a wedge-prism as an angle-gauge. Bruce (4) independently conceived the same idea later, and improved on it by a novel prism-rotation which automatically compensated for slope. He also first suggested the use of decentered lenses as magnifying angle-gauges.

To understand point-sampling, suppose that each tree in the forest were encircled at breast height by its own huge imaginary "ring" with a diameter 66 times as large as that of the tree. Naturally, many of these imaginary "rings" will overlap, so when a random sample point is located in the forest, it will probably lie inside a number of these "rings". If the "rings" inside which the point-sample falls are counted, it is obvious that the count will tend to be proportional to the amount of "ring" area per acre (allowing for overlaps), which in turn is exactly $(66)^2$ times as great as the amount of basal area on the area.

The probability of having a single random point-sample fall within any one of these "tree-rings" (i.e., of selecting that tree as a sample-tree or tally-tree) would be $(66)^2$ times the basal area of that tree divided by the total land area being sampled. A single random point-sample of the circular acre surrounding a tree of basal area = 1 square foot would have

$\frac{(66)^2}{43,560}(1) = 1/10$ (one chance out of ten) of falling within the "ring" of that tree. It would have 4 times as much chance of falling within the "ring" of a tree with twice the diameter or 4 times the basal area. No matter how many random point-samples might be taken on that acre, the larger of the two trees would tend to be counted 4 times as often as the smaller tree. There is no bias if the same tree is repeatedly sampled for basal area, volume, or frequency as long as the points are located at random or in a systematic manner not correlated with the tree population.

In order to combine a number of point-sampled trees and blow them up to a per-acre basis, it must be remembered that point-sampled trees are <u>not</u> sampled proportionally to their frequency as plot-sampling would do. Hence, their basal areas, volumes, frequency, etc. should <u>not</u> be given the same equal weight as in plot-sampling. Instead, before any further calculations are made, each point-sampled tree should have its basal area, volume, frequency, etc. weighted <u>inversely</u> as its probability of being sampled. Dividing each sample-tree basal area, volume, or frequency by its own basal area does this. Hence, for each point-sampled tree, $\frac{BA}{BA} = 1$, or $\frac{Vol}{BA}$, or $\frac{1}{BA}$ are the quantities which must be added to similar quantities from other sample trees in order to get an unbiased estimate of basal area density per acre, volume density per acre, or frequency per acre respectively. Of course, these sums must be divided by the number of sample points, and divided by a constant appropriate to the angle-gauge (dividing by $\frac{(66)^2}{43,560} = \frac{1}{10}$ in the preceding example is equivalent to multiplying by 10, the basal-area factor for an angle-gauge which delineates a "ring" with a diameter 66 times that of the tree it encircles).

If increment cores are taken from point-sampled trees, and if their past basal areas or volumes are estimated in the usual fashion, each <u>past tree quantity</u> must be divided by <u>present tree BA</u> before addition to obtain the sum of ratios per point for the trees now surviving. Instead of $\frac{BA}{BA} = 1$, $\frac{\text{past BA}}{\text{present BA}}$ will always be less than 1. Such a technique is exactly consistent with the one described in the preceding paragraph.

Another interesting phase of point-sampling theory involves permanently monumented point-samples for measuring growth. Where individual tree records are maintained for numbered trees and future reexaminations maintain tree identity, the same technique described above for bored trees can be employed, except that $\frac{\text{future BA}}{\text{present BA}}$ will always be greater than 1, etc. Such a system allows calculation of survivor growth, ingrowth, and total drain (including mortality) by initial tree and diameter classes, if desired. The next future reexamination will number and record newly qualifying trees, though they will not enter into calculation for the preceding periodic growth. Calculation of each subsequent periodic growth, however, will always use all trees tallied at the preceding examination, and basal areas at the start of each new period will be used in subsequent weighting.

If individual trees are not numbered and subsequently identifiable, permanent point-samples can still be used to measure net change in volume or basal area, though this cannot be broken down into survivor growth, ingrowth, and total drain. In this case, each retally at a point would include all newly qualified trees, and basal area at the time of tally should be used in weighting, just as in ordinary cruising.

Point-Sampling Application

In application, point-sampling is simple. At any given sampling point, the forester tallies all trees within whose "ring" his point falls. To estimate basal area per acre, he need merely count these trees. To approximate volume per acre, he need merely estimate the merchantable or total height of these trees (although more accurate volume estimates require either measuring each tree $\frac{\text{volume}}{\text{basal area}}$ ratio (7), or using a volume table to estimate this ratio). To estimate frequency per acre, he need merely measure diameter of each tree and give each tree a weight proportional to the squared reciprocal of its diameter.

The forester's angle-gauge will tell him whenever he is inside the "ring" of any particular tree. With the intercept-type angle-gauge, he tallies each tree whose d. b. h. appears larger than his angle-gauge crossarm or intercept. With the prism-type angle-gauge, he tallies each tree whose horizontally deviated d. b. h. -image viewed through the prism appears to overlap its simultaneously and directly viewed d. b. h. With either gauge, the d. b. h. of tallied trees must subtend an angle larger than that defined by the gauge itself.

Table 2 shows a wide range of angle-gauge sizes (in minutes and in prism-diopters) and gives the basal-area factors by which average tree count at a point must be multiplied in order to get basal area per acre. Basal-area factors are also needed in the various volume and frequency calculations (the $\frac{43,560}{(66)^2} = 10$ in the preceding example illustrates how the constant is a part of the probability associated with the gauge).

In addition to basal-area factors, Table 2 shows plot radius factors appropriate to each angle-gauge. These are useful in checking "doubtful" trees, where it is difficult to tell whether a sampling-point is inside or outside a particular "tree-ring". To qualify as a sample tree, distance from heart of tree to sampling point (in feet) must be less than tree d. b. h. (in inches) times plot radius factor. Thus, a 10-inch tree must be less than 27-1/2 feet distant from a sampling point in order to be tallied where a 104.18-minute angle-gauge is being used.

The last two columns in Table 2 are aids in constructing or calibrating an angle-gauge which will approximate a desired angle. The "Crossarm length factor" column indicates the appropriate ratio of $\frac{\text{crossarm length}}{\text{optical base length}}$ to use when constructing a stick-type angle-gauge. Thus, to construct a gauge with a basal-area factor of 50 and an optical base of 30 inches, the crossarm should be (.0678)(30) = 2.034 inches long. As a general rule, stick-type gauges with optical bases much shorter than 30 inches should not be used because the human eye cannot simultaneously focus on tree and crossarm of shorter bases. It will be noted that the crossarm length factor is very nearly equal to $\frac{\text{diopters}}{100}$.
The "Calibration distance factor" column in Table 2 indicates the distance X (in feet) at which the given angle-gauge will exactly subtend or deviate a rectangular target which is 1 foot wide. The use of the calibration distance (X) requires further explanation. Since it is usually impossible to purchase or construct a gauge having the exact specifications desired, it is important to know how to ascertain the appropriate factors for a gauge whose angle is imperfectly known. This is known as "calibrating" an angle-gauge. The appropriate factors for <u>any</u> particular angle-gauge (prism, stick, or milscale) can be readily determined by setting up (at eye-height) a rectangular target which is one foot wide, and by then backing off in a level plane along a line bisecting the target till the target exactly covers the angle laid off by the gauge (or is exactly deviated by the prism). If this calibration distance in feet from target center to angle vertex is called X (the vertex occurs

at the prism, or at the peephole of the stick, or at one focal length in front of the objective lens of a milscale instrument), then for that instrument:

$$\text{Basal-area factor (sq. ft. per acre)} = \frac{43,560}{1 + 4X^2}$$

$$\text{Plot radius factor (feet radius per inch of d.b.h.)} = \frac{\sqrt{1 + 4X^2}}{24}$$

$$\text{Crossarm length factor (any common units)} = \frac{1}{X}$$

Since many people are primarily interested in angle-gauges with basal-area factors near 10, Table 3 has been precalculated so that when X falls between the tabled limits of X, a corresponding accurate basal-area factor can be read directly for <u>all</u> values of X between the tabled interval. At least 10 estimates of X should be made, and the corresponding basal-area factors should be averaged to get an adequate instrument calibration (i.e., a reasonably reliable basal-area factor). For angle-gauges beyond the range of the precalculated values, it will be almost as accurate to average 10 or more values of X and to then calculate a single basal-area factor by the above formula. The coefficient of variation of individual basal-area factor calibrations is a good index for comparing precision of several different gauges or types of gauge.

Although an angle-gauge with a basal-area factor of 10 has been found free from brush-bias in the South, somewhat smaller angles have encountered difficulty with brush in the South. In exceptionally brushy localities or with large trees (as on the West Coast), somewhat larger angles may be desirable. The optimum size of angle with respect to the reciprocal of cost-times-sampling-variance has not been determined for any locality.

Point-sampling requires common sense and care. Failure to observe the following precautions will usually lead to erroneous estimates:

(1) Calibrate angle-gauge properly.
(2) Locate point-samples in an unbiased fashion (systematically or at random, so that margins are sampled in a representative fashion).
(3) Use a large enough angle to avoid brush bias (the masking of qualified trees by brush or intervening trees).

(4) Correct for slope of over 10 percent either by automatic gauge-correction, or by a correction factor (Table 4).

(5) Check enough doubtful trees (using tree d. b. h. and plot radius factor) so as to establish a combined personal and gauge correction factor. If the individual is unbiased and if instrument calibration has been carried out correctly, about half of doubtful trees should be tallied, but each person must establish a valid factor for himself and a particular gauge.

(6) Weight each accurately measured sample-tree basal area, volume, or frequency by the reciprocal of the probability of sampling it. At points well inside a tract, where 360^o sweeps are made with an angle-gauge, sampling probability is a simple function of basal area, as explained earlier. At points which fall near the boundaries of a tract, the usual 360^o sweep should be replaced by a 180^o, 90^o, or 60^o sweep toward the boundary from lines roughly paralleling the boundary and passing through the sample point. No tree occurring beyond the boundary should be tallied. The sector tallies should be multiplied by 2, 4, or 6 to compensate for reduced probability of sampling any tree in this zone. As a practical measure, where location of the boundary is not known exactly, it is usually more convenient to make the partial sweep toward the <u>interior</u> instead of toward the boundary. Only a negligible bias is introduced by using interior instead of exterior sweeps.

(7) Factors locally more valid than 60 or .005 should be derived where these short-cut approximations are not deemed satisfactory.

(8) Set proper fiducial limits for any estimates or comparisons, and use appropriate statistical techniques for analyzing differences.

Table 2.--Convenient angle-gauge sizes and factors for point-sampling standing trees

Angle-gauge size or strength		Basal area factor	Plot radius factor	Crossarm length factor	Calibration distance factor
Minutes	Prism-diopters	Sq. ft. per acre	Ft./inch d.b.h.		X
32.94	.96	1	8.696	0.0096	104.1
46.59	1.36	2	6.149	.0136	73.7
52.09	1.52	2-1/2	5.500	.0152	66.0
57.06	1.66	3	5.021	.0166	60.2
60.15	1.75	3-1/3	4.763	.0175	57.1
65.89	1.92	4	4.348	.0192	52.2
73.66	2.14	5	3.889	.0214	46.7
104.18	3.03	10	2.750	.0303	33.0
127.59	3.71	15	2.245	.0371	26.9
147.34	4.29	20	1.944	.0429	23.3
164.73	4.79	25	1.739	.0479	20.9
180.46	5.25	30	1.588	.0525	19.0
190.22	5.54	33-1/3	1.506	.0553	18.1
194.92	5.67	35	1.470	.0567	17.6
208.38	6.07	40	1.375	.0606	16.5
221.02	6.44	45	1.296	.0643	15.55
232.99	6.79	50	1.230	.0678	14.75
244.36	7.12	55	1.173	.0711	14.06
255.23	7.44	60	1.123	.0743	13.46
265.66	7.74	65	1.079	.0773	12.93
275.69	8.04	70	1.039	.0802	12.46
285.37	8.32	75	1.004	.0831	12.04
294.74	8.59	80	.9723	.0858	11.66
303.82	8.86	85	.9432	.0884	11.31
312.63	9.12	90	.9167	.0910	10.99
321.20	9.37	95	.8922	.0935	10.70
329.55	9.62	100	.8696	.0959	10.42
345.65	10.09	110	.8292	.1006	9.94
361.04	10.54	120	.7939	.1051	9.51
375.79	10.98	130	.7627	.1094	9.14
389.99	11.39	140	.7350	.1136	8.81
403.70	11.80	150	.7100	.1176	8.51
416.95	12.19	160	.6875	.1214	8.23
429.80	12.57	170	.6670	.1252	7.99
442.28	12.94	180	.6482	.1288	7.76
454.42	13.30	190	.6309	.1324	7.55
466.24	13.65	200	.6149	.1358	7.36

Table 3.--Appropriate factors for angle-gauge calibration, based on (X), the distance in feet at which a 1-foot target is exactly intercepted or deviated. Measure (X) as a perpendicular from center of target to prism, or to the eye if a stick-type gauge, or to a point one focal length in front of the objective lens if a stadia-type gauge

Limits of X	Basal area factor	Plot radius factor	Crossarm length factor	Limits of X	Basal area factor	Plot radius factor	Crossarm length factor
37.01				32.91			
	8.0	3.07	.0271		10.1	2.74	.0305
36.78				32.75			
	8.1	3.06	.0273		10.2	2.72	.0306
36.55				32.59			
	8.2	3.04	.0274		10.3	2.71	.0308
36.33				32.43			
	8.3	3.02	.0276		10.4	2.70	.0309
36.11				32.28			
	8.4	3.00	.0278		10.5	2.68	.0311
35.90				32.12			
	8.5	2.98	.0279		10.6	2.67	.0312
35.69				31.97			
	8.6	2.97	.0281		10.7	2.66	.0314
35.48				31.82			
	8.7	2.95	.0283		10.8	2.65	.0315
35.27				31.68			
	8.8	2.93	.0284		10.9	2.63	.0316
35.07				31.53			
	8.9	2.91	.0286		11.0	2.62	.0318
34.88				31.39			
	9.0	2.90	.0287		11.1	2.61	.0319
34.69				31.25			
	9.1	2.88	.0289		11.2	2.60	.0321
34.50				31.11			
	9.2	2.87	.0291		11.3	2.59	.0322
34.31				30.97			
	9.3	2.85	.0292		11.4	2.58	.0324
34.12				30.84			
	9.4	2.84	.0294		11.5	2.56	.0325
33.94				30.70			
	9.5	2.82	.0295		11.6	2.55	.0326
33.76				30.57			
	9.6	2.81	.0297		11.7	2.54	.0328
33.59				30.44			
	9.7	2.79	.0298		11.8	2.53	.0329
33.42				30.31			
	9.8	2.78	.0300		11.9	2.52	.0331
33.25				30.18			
	9.9	2.76	.0302		12.0	2.51	.0332
33.08				30.06			
	10.0	2.75	.0303		12.1	2.50	.0333
32.91				29.93			

Table 4. --Appropriate correction factors for basal area or volume per acre calculated from unadjusted angle-gauge tallies taken on a slope, where slope percent is measured at right angles to contour

Limits of percent slope	Slope correction factor	Limits of percent slope	Slope correction factor	Limits of percent slope	Slope correction factor
10.0		55.8		80.7	
	1.01		1.15		1.29
17.4		57.8		82.3	
	1.02		1.16		1.30
22.5		59.8		83.9	
	1.03		1.17		1.31
26.7		61.7		85.4	
	1.04		1.18		1.32
30.4		63.6		86.9	
	1.05		1.19		1.33
33.6		65.4		88.4	
	1.06		1.20		1.34
36.6		67.2		89.9	
	1.07		1.21		1.35
39.5		69.0		91.4	
	1.08		1.22		1.36
42.1		70.8		92.9	
	1.09		1.23		1.37
44.6		72.5		94.3	
	1.10		1.24		1.38
47.0		74.2		95.8	
	1.11		1.25		1.39
49.3		75.8		97.2	
	1.12		1.26		1.40
51.5		77.5		98.7	
	1.13		1.27		1.41
53.7		79.1		100.1	
	1.14		1.28		1.42
55.8		80.7		101.5	

Correction factor for steeper slopes is:

$$\sqrt{1 + \left(\frac{\text{Slope percent}}{100}\right)^2}$$

LITERATURE CITED

(1) Bitterlich, W.
1948. Die winkelzählprobe. Allgemeine Forst- und Holzwirtschaftliche Zeitung 59(1/2): 4-5.

(2) ________
1949. Das relaskop. Allgemeine Forst- und Holzwirtschaftliche Zeitung 60(5/6): 41-42.

(3) ________
1952. Das spiegel-relaskop. Oesterreichs Forst- und Holzwirtschaft 7(1): 3-7.

(4) Bruce, D.
1955. A new way to look at trees. Jour. Forestry 53: 163-167.

(5) Grosenbaugh, L. R.
1952. Plotless timber estimates--new, fast, easy. Jour. Forestry 50: 32-37.

(6) ________
1952. Shortcuts for cruisers and scalers. U. S. Forest Service Southern Forest Experiment Station Occasional Paper 126. New Orleans, La. 24 pages.

(7) ________
1954. New tree measurement concepts: height accumulation, giant tree, taper and shape. U. S. Forest Service Southern Forest Experiment Station Occasional Paper 134. New Orleans, La. 32 pages.

(8) MacKinney, A. L., and Chaiken, L. E.
1939. Volume, yield and growth of loblolly pine in the mid-Atlantic coastal region. U. S. Forest Service Southeastern Forest Experiment Station Technical Note 33, Asheville, N. C. Revised 1949.

(9) Müller, G.
1953. Das baumzählrohr. Allgemeine Forstzeitung 64(19/20): 249-251.

WOOD · WATER · FORAGE · WILDLIFE · RECREATION

FOREST SERVICE

U S

DEPARTMENT OF AGRICULTURE

1905 - 1955

50 YEARS

GOLDEN ANNIVERSARY